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Development And Testing of Arduino Based Autonomous Environmental Monitoring System

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Abstract

This paper presents the development of an Autonomous Environmental Monitoring System (AEMS) designed to track various environmental parameters. With the growing demand for autonomous monitoring systems in today's modern era, we propose an Arduino-based real-time hardware solution to measure parameters such as flame, temperature, humidity, and distance. The system leverages advanced and cost-effective electronic sensors and hardware to monitor these environmental factors. We developed individual sensor modules for each parameter and integrated them into a unified multi-sensor system through sensor fusion. The collected data is then displayed on a 16 × 2 LCD module. The result is a fully functional autonomous monitoring system, tested under laboratory environmental conditions using a compact, handheld device.

Keywords: Autonomous Environmental Monitoring System, Arduino, Fusion Sensors

Introduction

An autonomous environmental monitoring system consists of multiple sensors and transducers, along with signal conditioning and a recording/display device for storing and presenting the results. The sensors and transducers convert physical parameters or energy into electrical signals. Signal conditioning amplifies these analog signals to the required level before transmitting them to the monitoring station, where the signals are converted into digital form for processing. The data-acquisition device then records and displays the analog signals from the sensors and transducers, plotting the input and output signals on a chart recorder (or another analog device) or storing them in digital format. An effective autonomous monitoring system must be capable of continuously monitoring, recording, and controlling analog data from sensors and transducers. These systems are essential for industries that require reliable and accurate long-term data collection. The growing demand for autonomous monitoring systems is driven by the need to minimize human error in measurements. Modern data-acquisition technologies enable automatic data collection and control, reducing the risk of human error and enhancing accuracy. Currently, many complex industrial and laboratory measurements are performed through computer interfaces, ensuring precise results. Manual methods—such as reading outputs, recording results, and manipulating data by hand—introduce opportunities for error. Autonomous systems, however, eliminate these human-induced mistakes and deliver accurate results. One of the primary benefits of automated systems is the ability to handle large volumes of data with greater precision, reducing the need for repetitive measurements. Additionally, automated systems can monitor and adjust for changes in environmental conditions at the measuring location, which manual techniques cannot do as effectively. Traditional methods are more prone to errors from noise or other environmental factors, whereas automated systems can record data at cyclical intervals with higher accuracy and reliability **[1]**.

Related Works

Autonomous monitoring systems have been developed for a wide range of applications, including medical, industrial, automotive, and environmental monitoring. For instance, Hu et al. designed and evaluated the Haze Watch system, a Metropolitan Air Pollution Sensing System that integrates mobile sensor units, cloud computing, and mobile applications. This system measured air pollution in urban areas through a smart device-based model **[2]**. Shaban et al. developed an Air Pollution Monitoring System utilizing machine learning (ML) algorithms to create accurate forecasting models for multiple gases in urban environments **[3]**. Wonohardjo and Kusuma designed a mobile sensor-based air pollution mapping system, which uses the Internet of Things (IoT) and the

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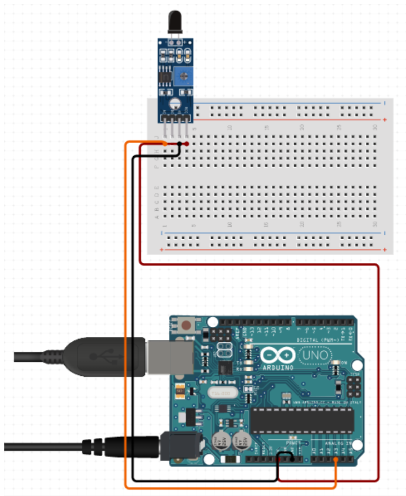
MQ-7 sensor to map carbon monoxide pollution levels **[4]**. Poma et al. developed an autonomous system to measure seawater temperature and pH levels, incorporating a graphene-based pH sensor, a thermistor, an electronic readout, and a smartphone for data display and analysis [5]. Rajalakshmi and Vidhya proposed a toxic environment monitoring system using sensors and Arduino, capable of detecting harmful gases like CO, H_2, CH_4, and other flammable gases through toxic gas sensors **[6]**. Hammami developed a smart environmental data monitoring system by building web-based temperature and humidity sensing devices **[7]**. Xia Geng et al. designed a greenhouse environment monitoring system, using a mobile-based IoT design to monitor conditions in agricultural settings **[8]**.

Experimental Setup

In this work, an Arduino Uno board was interfaced with a combination of multiple sensor modules to develop the autonomous environmental monitoring system. The key advantage of using Arduino in this design is its open-source nature, which includes both software and hardware components. Additionally, Arduino boards are widely available and well-suited for a variety of projects, such as reading data from sensors or transducers, controlling motors and electronic devices, and publishing data online **[9, 10]**. The development of the code for testing the multi-sensor system interfaced with the Arduino board, along with the testing procedures and results are summarized below.

(i) Flame sensor interfacing with Arduino

Flame sensors are commonly used in fire detection and safety alarm systems to identify the presence of flames. These sensors operate within the infrared (IR) wavelength range, typically between 760 nm and 1100 nm. Flame sensors can detect flames at a distance of up to 3 feet **[11]** and are equipped with an electronic circuit that includes an electromagnetic radiation receiver. When activated, the sensor detects electromagnetic radiation in the ultraviolet (UV) or infrared spectrum **[12]**. Specifically, the IR sensor is designed to detect low-frequency flickering IR radiation in the range of 1 to 15 Hz. The wiring diagram for interfacing the flame sensor module with the Arduino board is shown in Figure. 1. The VCC and GND pins of the flame sensor module are connected to the +5V and GND pins of the Arduino board, respectively. Additionally, the A0 and D0 pins of the flame sensor are connected to the A0 and digital pin 2 of the Arduino board

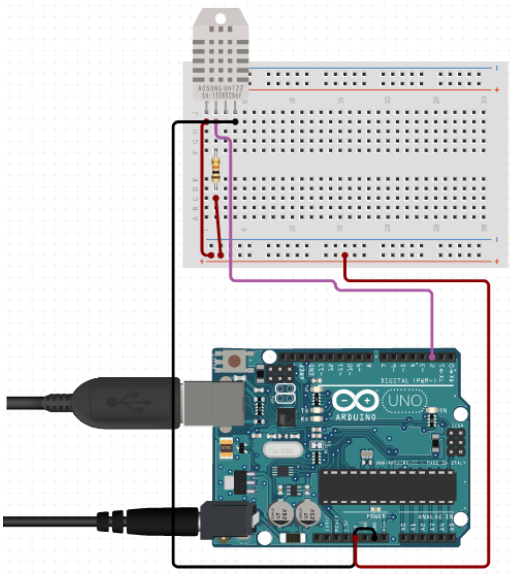


Figureure 1. Schematic diagram of Flame Sensor module interfaced with Arduino board

(ii) DHT sensor interfacing with Arduino

The Digital Humidity and Temperature (DHT) sensor was used to measure the temperature and humidity of the environment. The DHT sensor consists of a thermistor, a capacitive humidity sensor, and an Analog-to-Digital Converter (ADC). The thermistor is responsible for measuring the temperature, while the capacitive humidity sensor detects the humidity level in the surrounding air. The ADC converts the analog values of temperature and humidity into digital form, allowing the sensor to directly provide digital readings of both parameters **[13]**.

The connection diagram for interfacing the DHT sensor module with the Arduino board is shown in Figure. 2. In this setup, the positive (+ve), negative (-ve), and output pins of the DHT sensor module are connected to the +5V, GND, and A0 pins of the Arduino board, respectively.

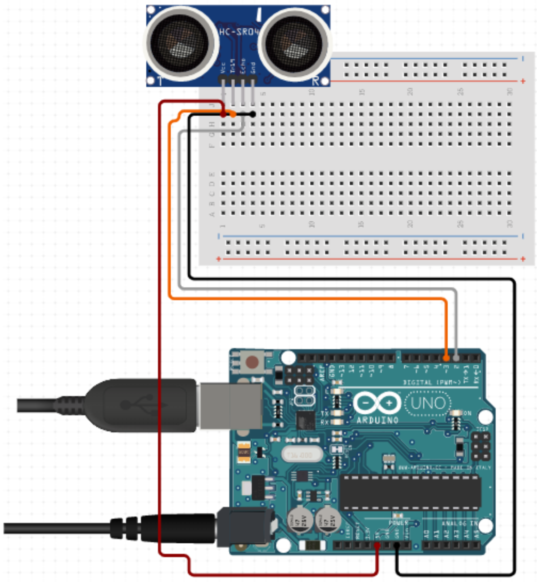


Figureure 2. Connection diagram of DHT sensor module interfaced with Arduino board

(iii) Ultrasonic sensor interfacing with Arduino

The ultrasonic sensor module is used to measure the distance to objects within the monitoring area. The sensor emits sound waves at an ultrasonic frequency greater than 20 kHz. These sound waves travel through the air, hit a specific object, and then return as an echo to the sensor's receiver. By measuring the time elapsed between the emission of the sound wave and the reception of the echo, the sensor can calculate the distance to the object. The speed of sound is then determined based on atmospheric conditions **[14]**.

The interfacing diagram for connecting the HC-SR04 ultrasonic sensor module with the Arduino Uno board is shown in Figure. 3. In this setup, the VCC, GND, Trigger (Trig), and Echo pins of the HC-SR04 module are connected to the +5V, GND, digital pin 7, and digital pin 8 of the Arduino Uno, respectively. The complete connection diagram for the Arduino-based autonomous monitoring system is shown in Figure. 4.



Figureure 3. Interfacing diagram of Ultrasonic Sensor module with Arduino Uno board

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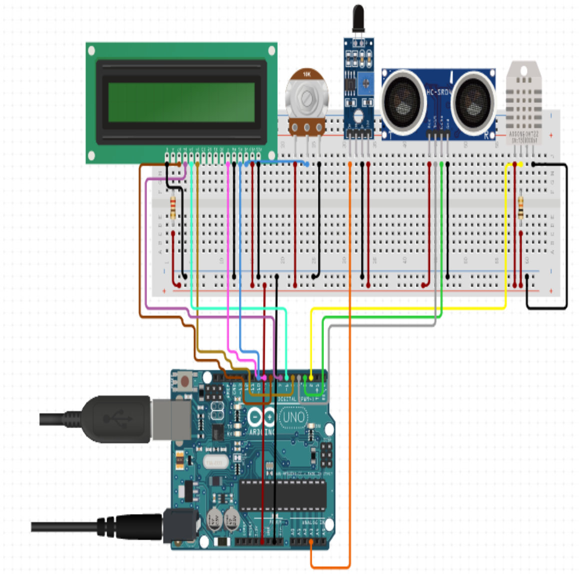


Figureure 4. Connection Diagram of the multi-sensor module of the autonomous environmental monitoring system

Results and Discussion

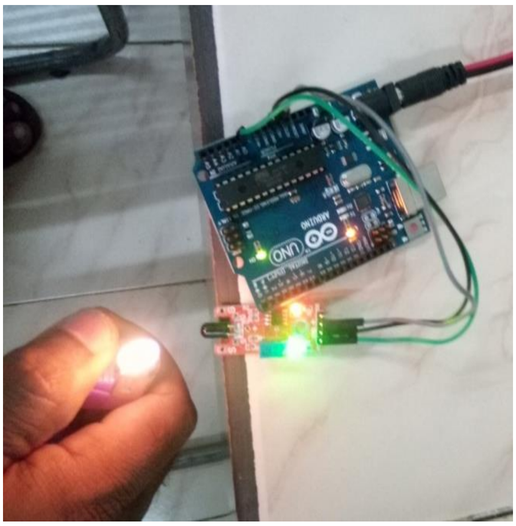
The results are divided into two main categories: i) testing of individual sensor modules, and ii) fusion of multiple sensor modules and testing.

i) Testing of individual sensor module

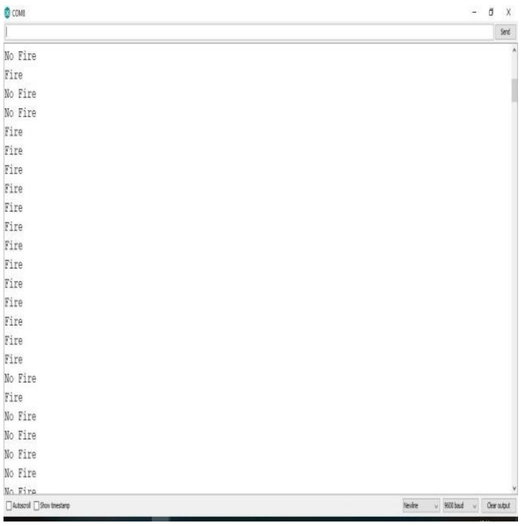
Initially, we developed and tested individual sensor modules for the proposed environmental monitoring application. The programs were written using the Arduino IDE and tested accordingly. The results were monitored in real-time using the serial monitor feature of the Arduino IDE under laboratory conditions.

a. Testing of the Flame sensor module

After executing the flame sensor code, a candle flame was brought close to the sensor. The flame sensor then detected the IR radiation emitted by the flame within its specified range, and the results were displayed on the Arduino output screen. The demonstration of the flame detection process and its corresponding results are shown in Figure. 5 and Figure. 6, respectively.



Figureure 5. Testing of Flame sensor



Figureure 6. Output of Flame sensing

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b. Testing of the DHT sensor module

After interfacing the DTH sensor, the program code for DTH module was executed on the Arduino board to check for any errors in the program. Once the program was confirmed to be error-free, the DHT sensors were exposed to various environmental conditions. The results were then acquired and displayed on the output screen. Figures. 7 and 8 show snapshots of the sensor module testing and the acquired results under laboratory conditions, respectively.

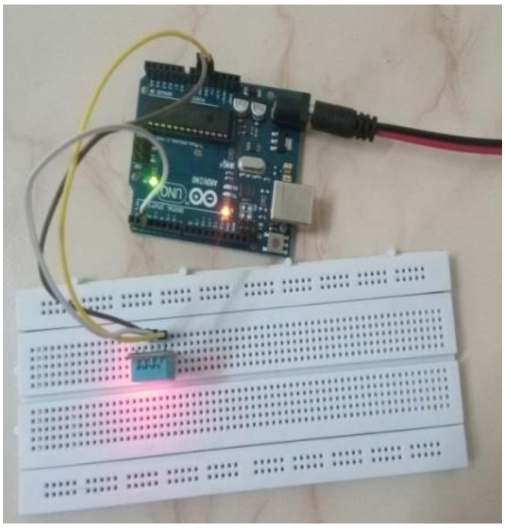

Figure 7. DHT sensor testing

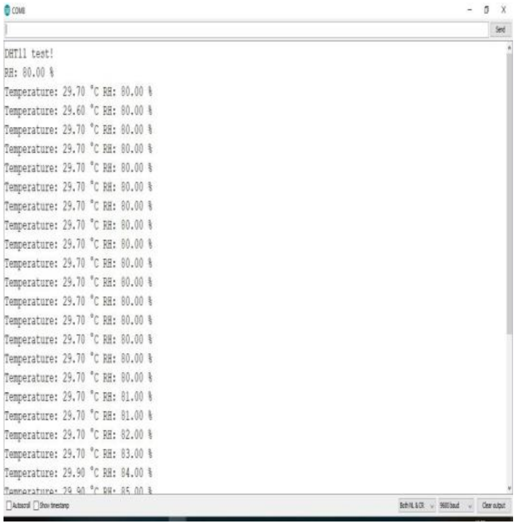

Figure 8. Output of DHT Sensor module

b. Testing of the Ultrasonic sensor module

After connecting the ultrasonic sensor module to the Arduino Uno board, the distance measurement code was executed in the Arduino IDE. Following program execution, an object in the sensor's line of sight was moved to test the sensor's ability to measure the distance to the object. The snapshots of the testing process and the acquired results are shown in Figures. 9 and 10, respectively.

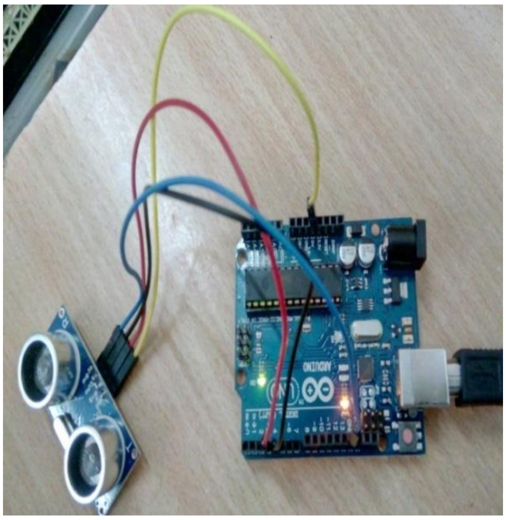

Figure 9. Testing of the Ultrasonic Sensor module

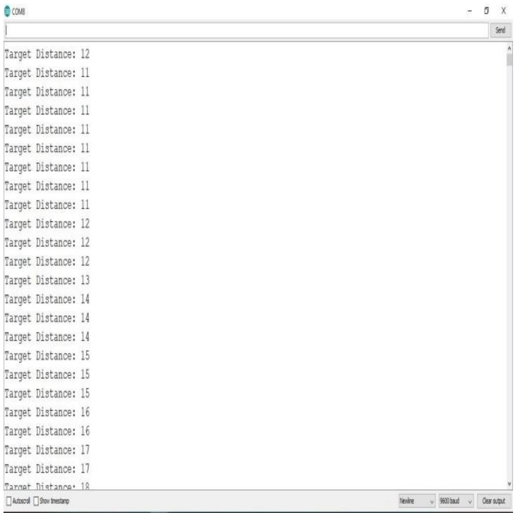

Figure 10. Output of Ultrasonic Sensor module

(ii) Fusion of multi-sensor modules and testing

To enable real-time monitoring of multiple parameters for the implementation of the autonomous environmental monitoring system (AEMS), all three sensor modules—flame, DHT, and ultrasonic—were interfaced simultaneously with the Arduino Uno board, as shown in Figure. 4. The code for each of the three modules was then integrated into a single program. The following sub-sections provide details on the hardware requirements, code implementation, sensor interfacing, and testing results.

a. Testing of multi-sensor modules

The Arduino Uno board was interfaced with the flame, DHT, and ultrasonic sensor modules, and the codes developed for each module were executed to test their individual responses. The outputs from all three sensor modules—flame, DHT, and ultrasonic—were collected by the Arduino Uno board and displayed on the screen of the autonomous environmental monitoring system, as shown in Figures. 11, 12, and 13, respectively. Finally, the circuits of all the multi-sensor modules were integrated and assembled onto a dedicated PCB for testing the proposed autonomous environmental monitoring system in a real-time environment. Figure. 14 shows the complete setup of the real-time Arduino-based autonomous environmental monitoring system.

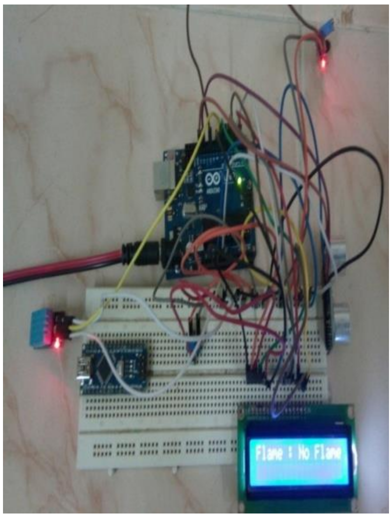

Figure.11. Output of Flame Sensor module

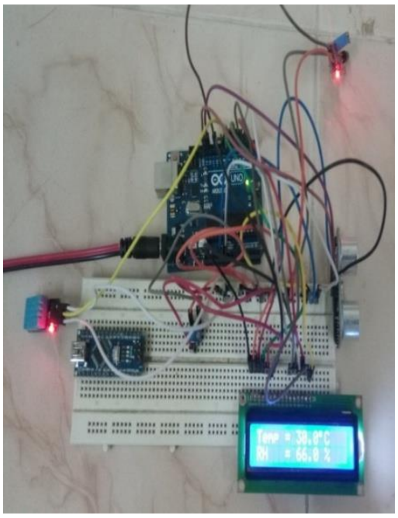

Figure.12. Output of DHT Sensor module

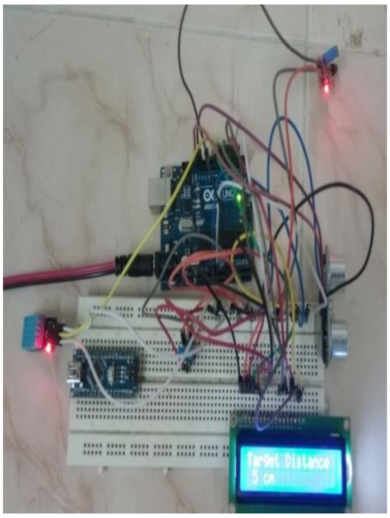

Figure.13. Output of Ultrasonic Sensor module

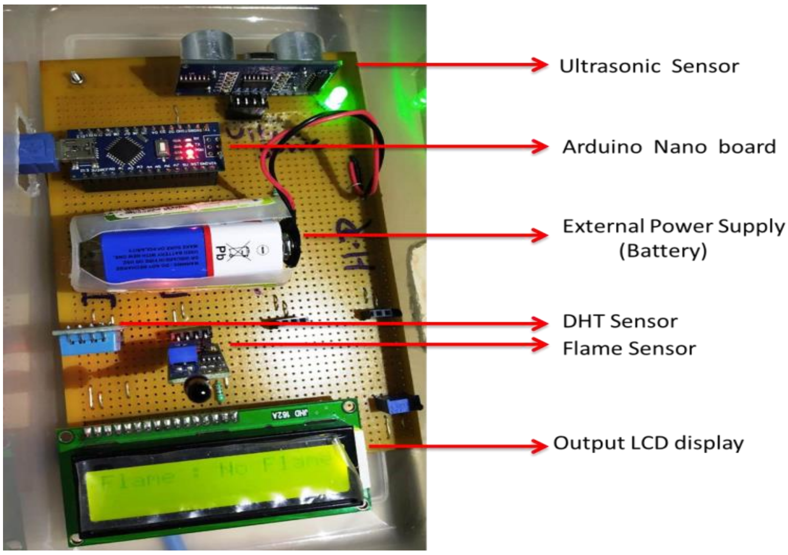

Figure.14. Complete Setup of the Autonomous Environmental Monitoring System (AEMS)

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Conclusion

In this work, three different sensor modules—flame, digital temperature and humidity (DHT), and ultrasonic—were selected to develop and demonstrate an autonomous environmental monitoring system. In the initial phase, each sensor module was interfaced individually with the Arduino Uno board, and corresponding code was developed using the Arduino IDE. After successfully testing the codes for each module, the results were found to be suitable for integration into a unified autonomous monitoring system. Subsequently, the sensor modules and their respective codes were integrated into a single program to implement the proposed autonomous monitoring system. Once the modules and code were combined on the Arduino Uno platform, the program was executed, and the results were displayed on a 16 × 2 LCD module. Upon execution of the multi-sensor system, a welcome message appeared to initiate the monitoring process. The system then displayed the safety precaution alarm, detecting the presence or absence of flame within the specified range. In addition, the system acquired and displayed temperature and humidity values from the surrounding environment on the LCD screen. The ultrasonic sensor measured the distance within the sensor's coverage area, and this data was also shown on the screen. As a result, the tested multi-sensor system functioned as a fully automated monitoring system, accurately measuring real-time data from the flame, DHT, and ultrasonic sensors, and displaying the results on the LCD screen interfaced with the Arduino Uno board. This demonstrated the effectiveness of the Arduino-based multi-sensor monitoring system, validating the concept of an autonomous environmental monitoring system.

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